INTRODUCTION

- The spin-wave approach is applied to the macroscopic properties calculation of the 2D paramagnetic is under low temperature and strong external magnetic field.
- The square and honeycomb lattices are considered:

- The external field is perpendicular the lattice or parallel the crystal axes [10] or [11].
- The node spins deviates from the field direction and form the spin waves due to dipole pair interaction:

SPIN WAVES DISPERSION

- The spin-waves energy surfaces for the cases when the field is orthogonal to the lattice (left) and parallel to it (along [10]-axis, right). Energy rises from black to white:

MACROSCOPIC PROPERTIES

- The specific heat $C_{SW}$ (curves 2, 3) is calculated:

  $C_{SH} = \frac{\hbar \omega_L}{k_B T} \exp\left(-\frac{\hbar \omega_L}{k_B T}\right)$

  $C_{SW}^{2D} = \frac{\hbar \omega_L}{k_B T} \exp\left(-\frac{\hbar \omega_L}{k_B T}\right)$

  $C_{SW}^{3D} = \frac{\hbar \omega_L}{k_B T} \exp\left(-\frac{\hbar \omega_L}{k_B T}\right)$

- It differs from the Schottky law $C_{SH}$ (curve 1) and can be found at temperatures <0.01 K.

  $\omega_L$ is the Larmor frequency.

SPIN DYNAMICS SIMULATION

- The spin-wave model is checked by direct numerical simulation of the 2D spin system under orthogonal magnetic field.
- The dipolar energy time dependence and its' Fourier spectrum:

- Average dipolar energy, its' deviation and spin wave spectrum interval:

  $E_d \approx 3.2 N S^2 \rho_d$, $\Delta E_d \approx 6.4 S \rho_d \langle n \rangle$

  $E_{SW} \in \left[\hbar \omega_L \left(1 - \frac{3}{2} S \rho_d\right), \hbar \omega_L \left(1 - \frac{1}{2} S \rho_d\right)\right]$

  $N$ is total spin number in lattice, $\langle n \rangle$ is average number of spin deviations per node, and $\rho_d = \text{dipolar pair energy} / \hbar \omega_L$.

  - The analytics matches the simulation data.

CONCLUSION

- The spin-wave approach is applicable in pure paramagnetic crystals.
- The external field direction permits to control material properties.